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CALCULATING THE RATE OF GROWTH OF FERRITE CRYSTALS DURING THE ISOTHERMIC DECOMPOSITION OF AUSTENITE

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/Figures referred to herein are appended./

When austenite in a hypoeutectic composition is cooled sufficiently slowly to a temperature below 723 degrees C, crystalline nuclei of a new phase (ferrite) start to form. The growth of ferrite consists of two processes: the reorganization of the rion lattice ($Fe_\gamma \longrightarrow Fe_\alpha$) and the redistribution of the concentration of carbon, which is considerably less soluble in the new phase than in the original phase. This case of lessening solubility fixes the limiting role played by the speed of diffusion of carbon atoms in austenite during the growth of ferrite crystals.

Actually, because of the need to decrease or at least to preserve the constancy of the free energy of the pertinent element in the system, it is necessary /1/ that the carbon concentration on the surface of the growing ferrite cystal have a value equilibrial for the given temperature

$$c\left[\rho(t), t\right] = c_{equi}, \tag{1}$$

where $\rho(t)$ is the radius of the crystal which increases in accordance with some law of growth. The origin of the spherical system of coordinates is located in the center of the crystal and it is considered as having the form of a true sphere.

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If examination is limited to crystals of visible dimensions, then the surface separating the new and old phases may be considered as having a slight curvature. In the first approximation, we disregard the influence of curvature and we assume that the equilibrial carbon concentration on the external side of the crystal's surface agrees with the value given in the diagram describing the equilibrium between iron and carbon when the GS line is extrapolated into the region of subcritical temperatures [2]:

$$c_{\,equi} = 0.8 + 0.013\,(723 - T) \qquad (2)$$

where T is the temperature at which the ferrite crystal begins to grow.

Condition (1) can be fulfilled only by equating (a) the amount of carbon separating out on the crystal surface, during an infinitesimal moment of time dt and outgoing in this same interval of time due to diffusion, to (b) the austenite not yet converted. The equation describing the conservation (balance) of mass on the boundary of the growing crystal can thus be written:

$$\left(c_{\,equi} - c_{n.ph}\right)\frac{d\rho(t)}{dt} = -D\left(\frac{\partial c}{\partial r}\right)_{r=\rho(t)}, \qquad (3)$$

where $c_{n.ph}$ is the carbon concentration in the new phase ($n.ph$) and D the coefficient of carbon diffusion in austenite.

We will assume that at the stage of ferrite-crystalline growth with which we are concerned the nuclei of the new phase grow independently of one another; that is,

if

$$c(\infty, t) = c_0, \qquad (4)$$

$$c(r, 0) = c_0, \qquad r > 0, \qquad (5)$$

where C_0 is the original carbon concentration in the austenite.

The process of carbon diffusion in austenite is governed by the equation

$$\frac{\partial^2 c}{\partial r^2} + \frac{2}{r}\frac{\partial c}{\partial r} = \frac{1}{D}\frac{\partial c}{\partial t}. \qquad (6)$$

The solution of equation (6) under conditions (1), (3), (4), and (5) can be affected, for example, by the method suggested by G. P. Ivantsov [3] (see Figure 1). It permits determining c(r,t) for t>0, $r \geq \rho(t)$ and $\rho(t)$. Without going into the various steps, the final result will be:

$$c(r,t) = c_0 + \left(c_{\,equi} - c_0\right)\frac{\dfrac{2\sqrt{Dt}}{r}e^{-r^2/4Dt} - \sqrt{\pi}\,\mathrm{erfc}\left(\dfrac{r}{2\sqrt{Dt}}\right)}{\dfrac{1}{\beta}\,e^{-\beta^2} - \sqrt{\pi}\,\mathrm{erfc}\,(\beta)}, \qquad (7)$$

where $\mathrm{erfc}\,(\beta) = \dfrac{2}{\sqrt{\pi}}\displaystyle\int_{\beta}^{\infty} e^{-\xi^2}d\xi;$

$$\rho(t) = 2\beta\sqrt{Dt}, \qquad (8)$$

β is the root of the transcendental equation:

$$\frac{c_{\,equi} - c_0}{c_{\,equi} - c_{n\,ph}} = 2\beta^2\left[1 - \beta\sqrt{\pi}\,e^{\beta^2}\mathrm{erfc}\,(\beta)\right] = F(\beta). \qquad (9)$$

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The function of $F(\beta)$ for $0 \leqslant \beta \leqslant 2$ is shown in Figure 1.

Thus, the speed of growth of a ferrite grain is

$$v(t) = \frac{d\rho(t)}{dt} = \frac{\beta\sqrt{D}}{\sqrt{t}}, \qquad (10)$$

where

$$\log D = -3.00 - 6.82\left(\frac{1}{273+T} - 5.8\cdot10^{-4}\right)\cdot 10^{3}, \qquad (11)$$

if D is expressed in square millimeters per second [2].

For example, let

$$c_0 = 0.49; \quad c_{nph} = 0.04; \quad T = 720^\circ C;$$

then

$$\frac{c_{equi} - c_0}{c_{equi} - c_{n.ph}} \cong 0.4.$$

From Figure 1 we find that

$F(0.8) \cong 0.4$; therefore $\beta \cong 0.8$.

In this case

$$v \cong \frac{940\cdot10^{-6}}{\sqrt{t}}\ mm/sec \qquad (12)$$

In Figure 2, the solid curve is derived from formula (12) and the dotted curve is determined on the basis of experiments performed by V. E. Neymark and R. I. Entin with the help of I. B. Piletska.

The completely satisfactory agreement between theory and experimental data indicates the accuracy of our initial assumptions.

The scheme set forth above may be applied to the calculation of the rate of growth of crystalline grains of the new phase and for other metallic systems.

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[Appended figures follow.]

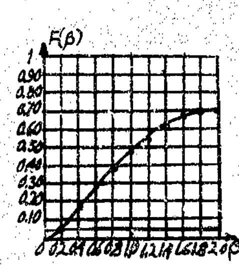

Figure 1

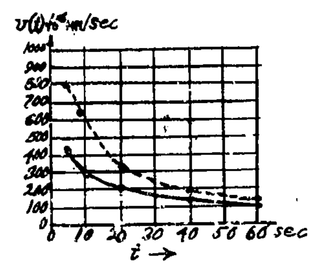

Figure 2

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